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Life Cycle Thinking in decision-making for sustainability: from public policies to private businesses

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Edited by: Giovanni Mondello, Marina Mistretta, Roberta Salomone Arianna Dominici Loprieno, Sara Cortesi, Erika Mancuso

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A case study of green design in electrical engineering: an integrated LCA/LCC analysis of an Italian manufactured HV/MV power transformer

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Abstract

The aim of this study is to present an experience of the application of the Sustainability Assessment Methodology to a traditional private business. It deals about a significant case study in which CESI S.p.A. applied an integrated LCA/LCC analysis to a 250 MVA HV/MV power transformer produced from the Italian Tamini Trasformatori S.r.l. and remanufactured from the traditional design- according to an innovative environmentally sustainable vision – changing the insulation material from mineral to ester oil. The study was the starting point to realize an Environmental Product Declaration and the preceding Product Category Rules, currently underway. Such an innovative and green product development tries to anticipate market demands, to improve the environmental performance and benefits of the energy transformation process, to increase the migration to bio and renewable sources solutions.

1. Introduction

Electric power has nowadays undertaken a critical role in modern society and in its functioning, and energy transmission is the fundamental connection between users and electricity producers. Power transformation acts an essential part in enabling the transmission and - at the same time – granting the highest efficiency and reducing the losses during the whole process. Power transformers functioning and manufacture is as well the ring of the chain to refer to, in order to try to further enhance efficiency and sustainability. It deals, however, of a mature product, which embodies a great potential thanks to its fundamental role, its relevant size and its worldwide spread.

In recent years eco-design principles have started to be applied also in the electrical engineering field, as attested by some works appeared in the literature (Debusschere et al., 2007; Berti et al., 2009; Tran et al., 2009; Lindner et al., 2010; Wei-Han et al., 2012; Spinosa et al., 2013), which is, nonetheless, still very scarce. However, only few of them are reporting dedicated LCA studies of power transformers (Berti et al., 2009; Jorge et al., 2012; Wang & Bessède, 2014), although some works are including transformers in their system boundaries (Jorge & Hertwich, 2013; Turconi et al., 2013).

This study relates of an exceptional case study of an Italian company that started applying *Ecodesign* concept to its activity, i.e. power transformers manufacturing. Tamini remanufactured a traditional 250 MVA HV/MV (high voltage/medium voltage) power transformer substituting - as insulation fluid - ester oil for mineral oil. Consequently, other changes had to be studied and applied to the transformer structure, in order to maintain the performances and to obey to the international standards in force. CESI was designated of the impacts analysis of the new product according to the Life Cycle Thinking methods, namely an integrated LCA/LCCA (Life Cycle Assessment and Life Cycle Costing Assessment) analysis.

Beside the assessment analysis, for this product it has been drawn up an environmental product declaration (EPD, ISO 14025:2010), now published as pre-registered EPD from Environdec, and drafted in compliance with the International EPD® System General Programme Instruction of the International EPD® System. The EPD will be officially registered after the publication of the document containing the Product Category Rules for that product class (the product is an oil-immersed transformer and as such is part of a subgroup of category *UN CPC 46121 Electrical transformers).* The previous PCRs were as a matter of fact expired as they had been registered in 2000 and de-registered since 2013 (www.environdec.com).

The importance of this experience of green design applied to private business lies in many factors, as already showed:

- the product studied is one of the first high power HV/MV transformer with vegetal oil on the market;
- the study of the sustainability assessment of such a product (and its publication through the EPD) is a pioneering one;
- it represents a green design example in a traditional sector and applied to a traditional and mature product, but which contains a great “improvement” potential affecting global market, due to its relevant dimensions and its essential function.

2. The “green” transformer

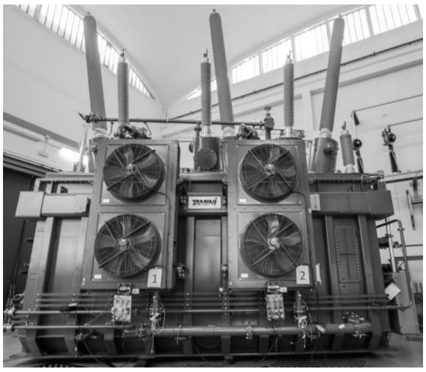

Figure 1: Tamini “green” transformer (ATR 15T037)

The product - the “green” 250 MVA autotransformer (Figure 1) - is an innovative environmentally sustainable and eco-efficient product, insulated with ester oil, and which commits to preserve environment and health, providing:

- an increase in the transformer life due to a longer life of the inside cellulose based insulation;

- a limited pollution risk (in case of spillage or loss, or during operation, installation and end-of-life phases) because ester oil is biodegradable and less toxic;
- a greater safety (toxicity and anti-fire), because ester oil has a higher flash point (more than double than the mineral oil one). This practically reduces to zero the fire ignition possibility due to a fault;
- a potential strong reduction of the site construction related impact (smaller distances between transformers and no longer indispensable collection tank, even if still required by legislation);
- an improvement of the efficiency and of the environmental performance, the power being equal.

3. Material and methodology

The LCA study presented in this document is a complete and detailed product LCA, as defined in the ISO standards. It is important to notice that input data and results exposed in this paper do not coincide exactly to those shown in the EPD, as the functional units and the system boundaries considered are different.

3.1. Goal and scope definition

The aim of the study was to evaluate the environmental impacts of an HV/MV transformer insulated with an innovative bio-material. The assessment was essentially conducted for external purposes, with green marketing goals. Accordingly, this policy led to the development of the EPD.

The study was performed in accordance with the methodology defined by the ISO standards (ISO 14040:2006, ISO 14044:2006) and adopted the "from cradle to grave" perspective. Accordingly, the analysis includes raw materials and components production, their transports and assembly, the use phase for an average lifetime at a certain load and at a certain efficiency, with the necessary ordinary and extra-ordinary maintenance, ending with the transformer dismantling and disposal.

3.1.1. Functional unit

The function of the system is the HV/MV transformation of a 250 MVA power at operating voltages of 400/135 kV. The functional unit adopted is therefore the life of a 250 MVA power transformer insulated with vegetable oil for 35 years of useful life (average life) at an average load of 70%.

3.1.2. System boundaries

The study uses the "from cradle to grave" perspective; therefore, it considers upstream, core and downstream phases (Figure 2).

The upstream phase includes components supply, namely their production, manufacturing and treatments. The core phase includes the following processes: components transport to the assembly site, transformer assembly at the factory, assembly factory consumptions and wastes; tests during the assembly and partial disassembly processes (the latter, in order to be sent to the operation site). The downstream phase includes the distribution, the use phase and the end-of- life. Distribution process considers the transformer transport - with its packaging - to the use site, and its installation. Use phase consists of losses related to the operation and functioning during the product average life, the ordinary maintenance and extraordinary maintenance. The end of life includes transformer dismantling and its subsequent disposal.

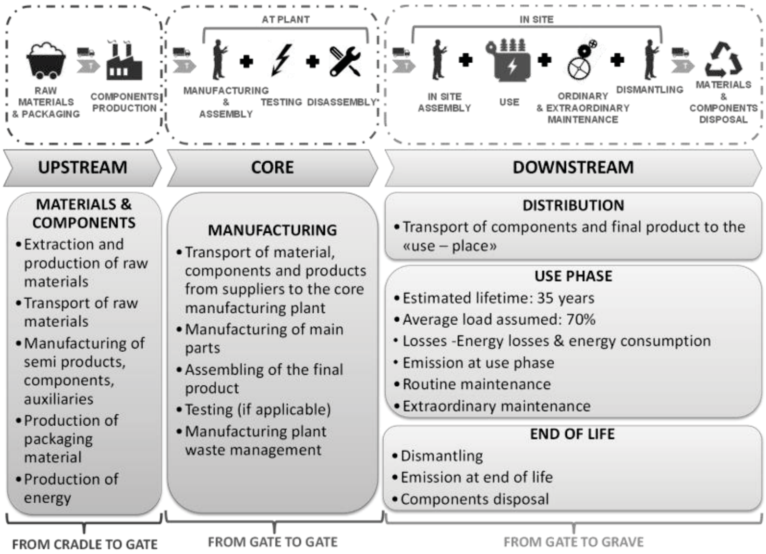

Figure 2: System boundaries

Other relevant boundaries are linked to time and place. The reference year for primary data is 2016. The geographical boundaries considered are different for phases: global for the upstream, Italian for the core, Italian for the downstream. The national one is just a possible downstream scenario - related to a real case study - but the company is selling worldwide; other geographical scenarios, although feasible, were not presented for brevity reasons.

3.1.3. Data quality

According to their quality level and to the source, the primary (and site specific) data used to perform this LCA study are those referred to: inputs and outputs of the assembly site (water, gas, electricity, waste, work force); timing and absorptions of the assembly activities; tests features; year detailed production; components detail, masses, materials and origins; production and treatments processes; packaging quantity and type; transformer destination; ordinary and extraordinary maintenance activities; disposal at end of life.

3.1.4. Study assumptions

The end-of-life scenarios of the materials to be disposed have been defined according to the national statistics (ISPRA, 2017).

The phase of raw materials transport from the place of extraction to the components production sites has been accounted for by using secondary data including general transport scenarios; for some minor flows these data were unavailable, then were excluded from the system boundaries.

3.1.5. Allocation rules

The allocation was necessary because in the reference period other transformers were produced in the plant. The applied allocations are based on physical quantities. The variable used to allocate total consumptions, wastes and packaging is the percentage corresponding to the green transformer power (250 MVA) compared to the total power produced in the reference year. The allocation used for energy absorption of manufacturing phase refers to the production worked hours with respect to the total working hours of the plant in the reference year.

A system expansion was considered to account for avoided products due to end of life recycling.

4. Life Cycle Inventory Analysis

The inventory analysis consists in the identification and quantification of data related to energy, water, flows and emissions into the environment for every phase of the life cycle of the system. The total weight of the “green” transformer (upstream phase) is around 220t, distributed among the components and materials listed in Table 1.

Table 1: Inventory analysis for components (left) an for materials (right)

Component	Weight	
	kg	%
Core	71610	32,09%
Oil filling	60700	27,20%
Tank assembly (Tank, Cover, Conservator,..)	40800	18,28%
Windings	24600	11,02%
Frame	7040	3,15%
Winding insulation	5400	2,42%
Fans	5292	2,37%
Magnetic shields	2170	0,97%
RIP Bushings HV	2100	0,94%
Connections supports	660	0,30%
Insulation frame/core	633	0,28%
Connections braidings	570	0,26%
Tap changer	555	0,25%
Handrail & gratings	500	0,22%
RIP Bushings MV	420	0,19%
RIP Bushings neutral	65	0,03%
Gaskets	50	0,02%

Materials	Weight	
	kg	%
Ferrosilicon	73672	33,01%
Soybean oil	60700	27,20%
Steel	51691	23,16%
Copper	24785	11,11%
Cellulose	3743	1,68%
Wood	2052	0,92%
Alluminium	1814	0,81%
Paper	1052	0,47%
Epoxy resin	837	0,38%
Fiberglass	738	0,33%
Polyester resin	480	0,21%
Plastic	372	0,17%
Iron alloy	342	0,15%
Glue	291	0,13%
Cast iron	176	0,08%
Insulating foam	171	0,08%
Silicone	129	0,06%
Electric camponents	71	0,03%
Rubber	50	0,02%

As it deals of an LCA of an high energy consuming product, energy plays a relevant role in the impact assessment; for every energy absorption of this life cycle, the reference was the Ecoinvent profile related to the Italian energy mix (“Electricity, high voltage {IT}| market for | Alloc Rec, U”). A relevant part of the impacts, as shown later, is due to energy losses during the transformer life-time, as assessed according to legislation limits and carried out taking into account impacts generated by the production of the electricity required to offset them.

5. Impact Assessment

This LCA study was performed using the SimaPro 8.0.5 Software. The source of eco-profiles of the materials is the Ecoinvent database (also available in the SW itself).

The environmental impacts were assessed using the multi-category method “Recipe Midpoint Hierarchist / Europe (v1.12). This method links the inventory analysis results to 18 impact categories, so it covers a broad category range. In addition, the energy assessment (“Cumulative Energy Demand” method, v.1.09, CED) and the system CO_2 content (“Greenhouse Gas Protocol” method, GGP) are presented.

The results of the environmental analysis are integrated with a simplified economic assessment. The Environmental LCC is based on the same model, system boundaries, functional unit, on the product whole life cycle as the LCA. Both the assessments are performed through the SimaPro SW; a specific method (“LCC, v.1”) and database was built on puropose. To evaluate a product life cycle costing (Hunkeler et al., 2008) some costs (maintenance) needed to be updated to their net present value (“values discount”).

6. Results

6.1.1. LCA Output

Almost all the categories, as shown in Table 2, are dominated by downstream phase, except “marine eutrophication” and “metal depletion”, in which the upstream phase prevails, due to the production of the components, for the significant amount of metals involved). The use phase is far and wide dominant in the other considered categories, because of the impacts generated by the production of the electricity - necessary to compensate the losses - through the considered mix.

The core phase is almost always negligible, with the exception of the two categories linked to aquatic ecotoxicity, “freshwater ecotoxicity” and “marine ecotoxicity”, due to the waste disposal processes impacts of some waste generated in the assembly plant.

Lastly, the end-of-life phase gives a negative contribution in all impact categories except those connected to aquatic toxicity. The “positive” effects of this phase are attributable mainly to the processes of recycling and reuse of materials.

According to the CED method assessment (Table 3), in each considered phase the non-renewable energy content prevails; however, the use of a biological fluid instead of one from fossil source causes enhances the renewable energy content.

Analogously, the content of CO_2 stored in the “green” system increases (Table 4) moving from the traditional transformer to the “green” one. Therefore the green transformer has a good CO_2 storage capacity (the amount of carbon dioxide stored in the system for its useful life represents an equivalent amount of CO_2eq seized from the environment for a significant number of years, 35). In addition, there is an increase in the ratio “stored CO_2eq” on “emitted CO_2eq”.

Table 2: Detailed contributions of the "green" transformer life phases to ReciPe impact categories

Impact Category	M.U.	Total	Upstream		Core		Downstream	
Climate change	kg CO2 eq	6,4E+07	9,3E+05	1,5%	1,1E+05	0,2%	6,3E+07	98,4%
Ozone depletion	kg CFC-11 eq	8,4E+00	5,4E-02	0,6%	1,5E-02	0,2%	8,4E+00	99,2%
Terrestrial acidification	kg SO2 eq	2,4E+05	5,1E+03	2,1%	4,5E+02	0,2%	2,3E+05	97,7%
Freshwater eutrophication	kg P eq	1,0E+04	1,0E+03	10,1%	1,2E+01	0,1%	9,2E+03	89,8%
Marine eutrophication	kg N eq	8,4E+03	7,6E+03	91,2%	1,5E+01	0,2%	7,2E+02	8,6%
Human toxicity	kg 1,4-DB eq	9,4E+06	1,6E+06	17,1%	1,4E+04	0,1%	7,8E+06	82,7%
Photochemical oxidant formation	kg NMVOC	1,4E+05	3,8E+03	2,7%	3,5E+02	0,2%	1,4E+05	97,1%
Particulate matter formation	kg PM10 eq	7,4E+04	3,2E+03	4,3%	1,5E+02	0,2%	7,1E+04	95,5%
Terrestrial ecotoxicity	kg 1,4-DB eq	2,3E+03	6,7E+02	29,6%	7,9E+00	0,4%	1,6E+03	70,0%
Freshwater ecotoxicity	kg 1,4-DB eq	3,4E+05	4,2E+04	12,5%	1,7E+04	4,9%	2,8E+05	82,6%
Marine ecotoxicity	kg 1,4-DB eq	3,0E+05	4,1E+04	13,7%	1,4E+04	4,7%	2,5E+05	81,6%
Ionising radiation	kBq U235 eq	1,1E+07	9,1E+04	0,8%	1,3E+04	0,1%	1,1E+07	99,0%
Agricultural land occupation	m2a	1,5E+06	5,8E+05	38,5%	1,7E+03	0,1%	9,3E+05	61,4%
Urban land occupation	m2a	2,1E+05	1,4E+04	6,7%	1,1E+03	0,5%	1,9E+05	92,8%
Natural land transformation	m2	9,7E+03	9,3E+02	9,6%	2,2E+01	0,2%	8,8E+03	90,2%
Water depletion	m3	4,3E+05	1,7E+04	4,0%	6,9E+02	0,2%	4,1E+05	95,8%
Metal depletion	kg Fe eq	1,7E+06	1,4E+06	84,6%	1,5E+03	0,1%	2,6E+05	15,4%
Fossil depletion	kg oil eq	1,9E+07	1,9E+05	1,0%	3,4E+04	0,2%	1,9E+07	98,8%

Table 3: Contributions of the CED method

	Upstream		Core		Downstream		Total	
	MJ	%	MJ	%	MJ	%	MJ	%
Primary energy non renewable **PE-Nre**	9,89E+06	68%	1,68E+06	92%	9,80E+08	87%	9,92E+08	87%
Primary energy renewable **PE-Re**	4,57E+06	32%	1,48E+05	8%	1,43E+08	13%	1,47E+08	13%
Total	1,45E+07	1%	1,83E+06	0%	1,12E+09	99%	1,14E+09	

Table 4: Contributions of the GGP method

Impact category	M.U.	Total	Upstream	Core	Downstream
Total	kton CO_2	63817,2	703,6	117,5	62996,1
Fossil CO2 eq	kton CO_2	63502,9	749,9	109,7	62643,3
Biogenic CO2 eq	kton CO_2	1324,8	56,1	8,9	1259,8
CO2 eq from land transformation	kton CO_2	6,7	169,0	0,0	-162,2
CO2 uptake	kton CO_2	-1017,1	-271,3	-1,1	-744,7
%(uptake/emissions)	%	*1,6%*	*27,8%*	*0,9%*	*1,2%*

6.1.1. LCC Output

According to the LCC method, the predominant economic impact is due to electricity costs (67,8%), whose main contribution comes from the energy consumption necessary to compensate the losses in the use phase, in line with the LCIA results. Other quantitatively major contributions are components (22,1%) and personnel (9,7%) costs.

7. Conclusions

The study presented the results of an integrated environmental and economic analysis on a high energy consuming traditional object, remanufactured in an "eco-friendly" way. The results locate the main impacts – both economic and environmental – on the use phase, due to the energy consumptions necessary to compensate the transformation losses. In conclusion, the work demonstrates that there is room also for green design on market-mature and traditional products with positive consequences on their environmental performances.

References

Scientific journal:

Berti, R., Barberis, F., Rossi, V. & Martini, L. Compararison of the ecoprofiles of superconducting and conventional 25 MVA transformers using the life cycle assessment methodology. Proceedings of the IET Conference Publications, 2009.

Debusschere, V., Ben Ahmed, H., Multon, B. & Ieee. Eco-design of electromagnetic energy converters: The case of the electrical transformer. Proceedings of the Ieee Iemdc 2007: Proceedings of the International Electric Machines and Drives Conference, Vols 1 and 2, New York, 2007, Ieee, Pp. 1599-+.

Jorge, R.S., Hawkins, T.R. & Hertwich, E.G. (2012) Life cycle assessment of electricity transmission and distribution-part 2: transformers and substation equipment. International Journal of Life Cycle Assessment, 17, 184-191.

Jorge, R.S. & Hertwich, E.G. (2013) Environmental evaluation of power transmission in Norway. Applied Energy, 101, 513-520.

Lindner, C., Treier, L., Meyer, F., Pohlink, K., Dardel, T., Kieffel, Y. & Huet, I. Environmental analysis of different technologies for a Swiss high-voltage substation. Proceedings of the 43rd International Conference on Large High Voltage Electric Systems 2010, CIGRE 2010, 2010.

Spinosa, A., Kieffel, Y. & Huet, I. (2013) Eco-design in high voltage applications, illustration by two concrete cases. European Journal of Electrical Engineering, 16, 511-528.

Tran, T.V., Brisset, S & Brochet, P. (2009) Approaches for the ecodesign in electrical engineering application to a safety transformer. 6th International Multi-Conference on Systems, Signals and Devices. SSD 2009, art. no 4956695, 1-8

Turconi, R., Simonsen, C.G., Byriel, I.P. & Astrup, T. (2013) Life cycle assessment of the Danish electricity distribution network. The International Journal of Life Cycle Assessment, 19, 100-108.

Wang, W. & Bessède, J.L. (2014) Life cycle assessment of equipment for electricity transmission and distribution networks. Eco-friendly Innovation in Electricity Transmission and Distribution Networks, 123-133 pp.

Wei-Han, W., Tao, L., Ymg-Hao, L. & Shui-Hua, G. (2012) Evaluation on contribution of steel products to environmental improvement from life cycle assessment perspectives. Journal of Shanghai Jiaotong University (Science), 17, 370-372.

Monograph:

Frischknecht, R.; Jungbluth, N.; Althaus, H.J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; Spielmann, M. 2007. Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3, Swiss centre for Life Cycle Inventories, Dübendorf, Switzerland.

Hunkeler, D, Rebitzer, G, Lichtenvort, K, (edts.) 2008. Environmental Life Cycle Costing. SETAC publications, New York, USA.

ISPRA (2017) Rapporto Rifiuti Urbani 272/2017

PRé a.a.v.v., 2015, SimaPro Database Manual Methods library; Report version: 2.8

WBCSD & WRI. 2009. Product Life Cycle Accounting and Reporting Standard. Review Draft for Stakeholder Advisory Group. The Greenhouse Gas Protocol Initiative. November 2009

Standard or rules:

UNI EN ISO 14025:2010 Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures

UNI EN ISO 14040/14044:2006 - Environmental management - Life cycle assessment - Principles and framework (14040) and Requirements and guidelines (14044).